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Visibility Analysis of the Roman Communication Network in Southern Scotland

Kathryn Murphy[1], Bruce Gittings[2], and Jim Crow[3]
[1] Institute of Geography, School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh, UK EH8 9XP, kathrynmurphy@hotmail.ca
[2] Institute of Geography, School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh, UK EH8 9XP, bruce@ed.ac.uk
[3] School of History, Classics & Archaeology, University of Edinburgh, William Robertson Wing, Old Medical School, Teviot Place, Edinburgh, UK EH8 9AG, jim.crow@ed.ac.uk

Corresponding Author:
Kathryn Murphy
Institute of Geography
School of Geosciences
University of Edinburgh
Drummond Street
Edinburgh, UK
EH8 9XP
kathrynmurphy@hotmail.ca
+44 (0) 747 325 6608

Abstract: This paper uses GIS and visibility analysis to examine if Rubers Law fits into the known Roman communication and infrastructure network of towers, forts, camps and roadways in southern Scotland. Rubers Law is a prominent hill in the Scottish Borders with an extensive archaeological history, and the discovery of approximately 30 Roman building stones on the summit in the early 20th century led to the conclusion that it had been the site of a Roman signal station, despite a lack of concrete evidence for a Roman occupation. Visibility and intervisibility from the Roman towers was analysed using four types of viewshed analysis: regular, cumulative, fuzzy, and probable. The results were analysed to determine what would be visible from Rubers Law from a tower between 7m and 10m high. The various viewshed methods were also compared; it was determined that regular and cumulative viewsheds over predict visibility, while fuzzy and probable methods are more robust. Based on this analysis, a tower on Rubers Law could have been a major relay station, passing messages from Brownhart Law and Craik Cross Hill to Eildon Hill North and Newstead Roman Fort.

Key Words: Visibility analysis; GIS; viewshed; Roman Britain; Scottish archaeology; signalling; Rubers Law

1 Introduction

Rubers Law is a prominent hill in the Scottish Borders. It rises to the height of 424m, and sits between Hawick and Jedburgh. The first formal exploration of the archaeological features on the summit of Rubers Law took place in the early 20th century, when Alexander O. Curle conducted a survey of the site. While he did explore the remains of the early Iron Age hill fort and what he called the 'Dark Ages' (in reality an early Medieval) hill fort, Curle's main focus was on his discovery of dressed Roman building stones in the ruins of the Medieval hill fort walls (Curle, 1905). He returned to the site in 1906 to continue his investigation of these Roman stones, and conducted a small excavation on the summit of the hill. Despite not finding any other evidence for a Roman occupation of the hill, Curle concluded that the approximately 30 Roman stones that he had found, plus the prominence of their location, represented the remains of a Roman signal tower on the summit of Rubers Law (Curle, 1907). No other detailed archaeological investigation has taken place on Rubers Law, and this conclusion has carried forward in the literature (Bosanquet, 1928; Curle, 1932; MacDonald, 1939; St. Joseph, 1948; Stevenson, 1948; RCAHMS, 1956; Feachem, 1963; Martin, 1965; Robertson, 1983). This paper will attempt to address some of the questions related to Rubers Law's connection to other known Roman signal stations in southern Scotland, and how the site may have connected with the Roman communication and infrastructure network in the region. This investigation will focus on the use of a variety of viewshed analyses (regular, fuzzy, cumulative and probable) to place Rubers Law in the Roman context and to understand what could be seen from a potential signal tower on the summit of the hill. Based on this analysis, this paper will argue that during the Roman occupation, the purpose of Rubers Law fell into one or more of the following categories: no significant purpose, minor tower with localised visibility, major tower acting as a relay station between other towers in the region and Newstead Roman fort, or a communication link between Hadrian's Wall and other infrastructure to the north.

2 Research Questions

This study will look to answer the following questions.

- What is visible from Rubers Law? Is Rubers Law a logical location for a Roman signal tower?
- How do the results from the different viewshed methods compare? Do they provide supporting or contradictory results?
- How can the different viewshed methods be used together to provide a better picture of the visibility from and placement of archaeological sites?

3 Background

3.1 Rubers Law and Other Roman Infrastructure in southern Scotland

With the discovery of approximately 30 dressed Roman facing stones at the summit of Rubers Law, the assumption was made that there had been a Roman structure on the summit whose building materials were reused in the early medieval hill fort. Due to its elevated position, Curle (1905) concluded that this structure must have been a signal station (see Murphy, 2016 for a re-examination of the stones). While this is a possibility, no analysis has been conducted to establish whether Rubers Law actually fits into the known communication and signalling network in the region (see Figure 1). Other known Roman signal stations in southern Scotland include Beattock Summit (Maxwell, 1976), Craik Cross Hill (Martin, 1965; Breeze, 1979; RCAHMS, 1997) Eildon Hill North (Steer, 1952; RCAHMS, 1956b; Martin, 1965), Ewes Doors (Burnham et al, 1997; RCAHMS, 1981; RCAHMS, 1997; RCAHMS, 2015), and White Type (Crawford, 1939; St. Joseph, 1952; RCAHMS, 1978; RCAHMS, 1997). Brownhart Law (St. Joseph, 1948; RCAHMS, 1956; Martin, 1965) had previously been identified as a signal station, but is now classified as a fortlet. It is included in this study due to its prominent location, excellent visibility, and the ability to stand watch and send or receive signals from the top of the fortlet walls. Carmaben Hill (St Joseph, 1952) and Butterhole Brae (St. Joseph, 1951) have been identified as possible Roman towers, but no further study has taken place to confirm this classification; these sites are included in this study with an understanding of the limitations of these sites. Barron's Pike (Topping, 1987; Frere et al., 1989 Woolliscroft, 1990) and Robin Hood's Butt (Nichols (ed.), 1818; Haverfield, 1901; Richmond, 1933; Topping, 1987) are located just across the modern border in northern England, and are included in this study in order to investigate potential communication between Hadrian's Wall and southern Scotland. The main Roman fort in the region is Newstead. It is located 33 km north of Rubers Law, just below the Eildon Hill North signal station, and is found along the route of Dere Street, the main Roman road in eastern Britain (Hunter and Keppie, 2012).

Unfortunately, the tower structures remain undated, and therefore, it is presumed for this exercise that they were contemporary with one another. It should also be noted that land cover can have an effect on intervisibility; if the area was heavily forested, this could affect the ability of the towers to see each other (Sansoni, 1996). Due to the height of the towers and the prominence of the study sites, it is assumed that the Romans would be able to see above any trees, and this is accounted for in the analysis through the use of offset heights. Atmospheric conditions have also changed since the Roman period, with significant increases in airborne pollution since the Industrial Revolution (Vitousek et al, 1997) and light pollution following the advent of artificial lighting in the 20th century (Narisada and Schreuder, 2004), and this too will have had an impact on the visibility experienced during fieldwork.

There is also some discussion about the true purpose and the labelling of Roman towers; whether they were primarily for signalling (and are therefore signal stations), or if they were lookout points (and therefore called watchtowers) (Southern, 1990; Hanson and Friell, 1995). For the remainder of this paper, the previously mentioned signal stations will be referred to as towers.

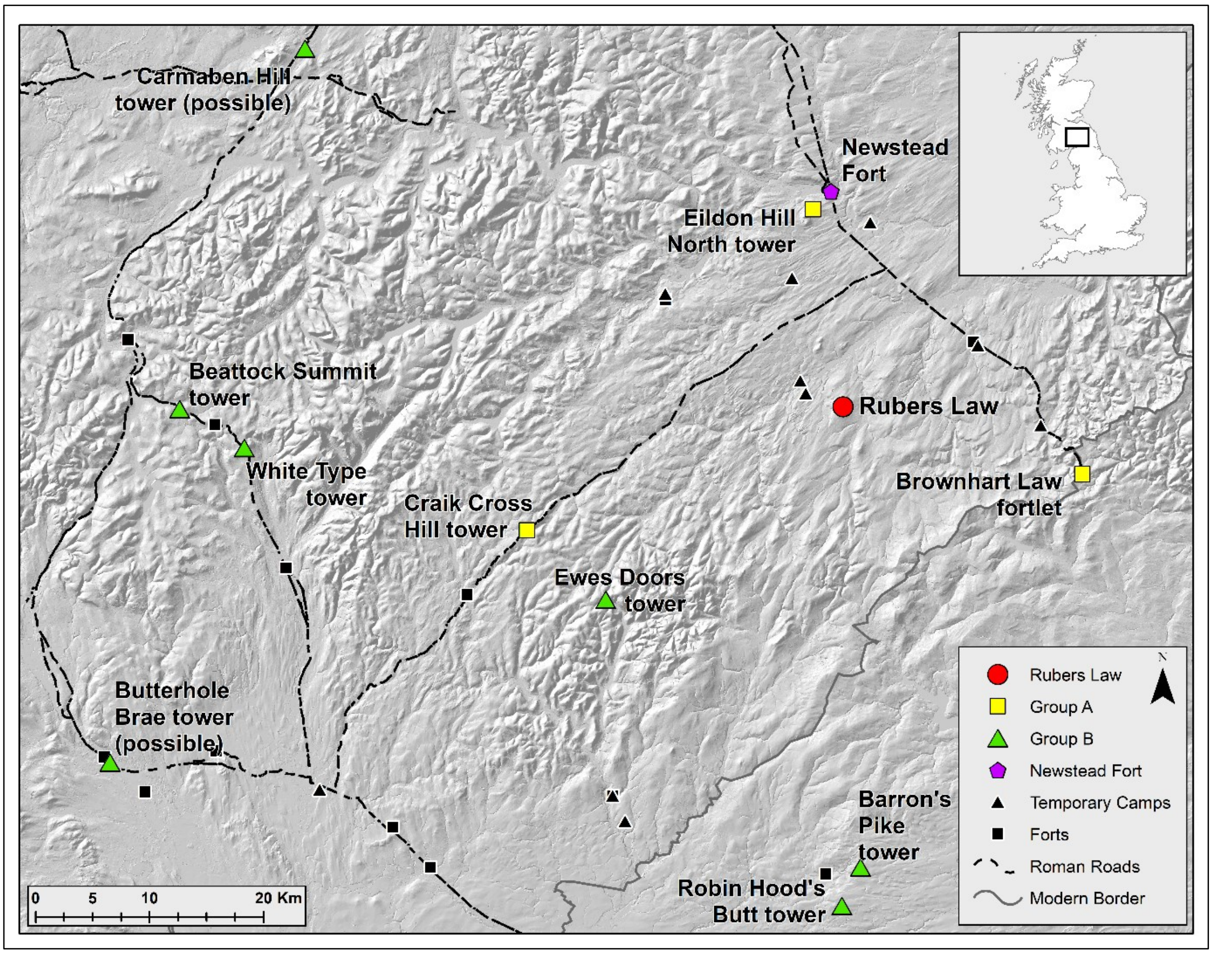

Figure 1: Overview map of the study area, including Rubers Law, other Roman tower sites, and forts, temporary camps and roads within the visible area

3.2 Roman Signalling Methods

Archaeologists have been identifying sites across the Roman Empire as signal towers for over a century, but our understanding of the role played by these sites and the techniques used to communicate with other Roman sites in the vicinity remains limited. Some research has been conducted looking into the different signalling methods that the Romans could have used between the signal towers (Donaldson, 1988; Southern, 1990; Woolliscroft, 2001). The different methods have been described by ancient writers, with some signalling methods seeming to have been put into practical use, while others are much more theoretical in nature (Homer, *Iliad*; Thucydides, *The Peloponnesian War IV*, 424 BC; Polybius, *Histories X*, 2nd century BC; Philon, *Mechanica VII*, 3rd century BC, and others in Woolliscroft, 2001). Unfortunately, since most of the surviving texts that discuss signalling in the Ancient world were written by members of the upper class, they provide descriptions of the signalling methods, but very little related to the technical or mechanical details of how they functioned (Woolliscroft, 2001). The most likely signalling method, and the easiest to put into practice, is the use of fire beacons (Woolliscroft, 2001). This method can be used by single towers, or passed along a line of towers to transmit a message over a longer distance. Unfortunately, it is a binary system (the fire is either lit or extinguished at night, and smoke or no smoke during the day), and therefore could really only be used to send simple, pre-defined signals (Woolliscroft, 2001). Other, much more complicated and less practical signalling methods include synchronised water clocks, signalling by torch combinations, semaphore, flare signals, heliographs, and carrier pigeons (Donaldson, 1988; Woolliscroft, 2001).

3.3 Visibility Analysis in Archaeology

Factors such as visibility and intervisibility are often taken into consideration when analysing archaeological sites and their landscapes, but these aspects were not fully and systematically explored until the use of Geographical Information Systems (GIS) became more commonplace in the field (Wheatley and Gillings, 2002). Visibility analysis methods include viewshed, which calculates which cells in a raster are visible from an observer point based on elevation (De Montis and Caschili, 2012), and line of sight, which calculates what is visible on a straight line between two points (Wheatley and Gillings, 2002). Viewsheds are used to check what areas of the landscape are visible from a particular site or location, while line of sight is used to check the intervisibility of two archaeological sites or between a site and an important feature in the landscape. These analysis methods are used by archaeologists as a way to understand some of the thought processes that may have gone into site placement (Bongers et al, 2012; Marsh and Schreiber, 2015), to assess the intervisibility of sites and features in the landscape (Supernant, 2014), and to assess the defensibility of sites (Martindale and Supernant, 2009; Sakaguchi et al., 2010). Due to concerns about the legitimacy of the results from regular, binary viewshed analysis (Fisher, 1991; Wheatley and Gillings, 2000), other viewshed methods have been developed. These include: cumulative viewshed, which uses map algebra to calculate how many times a raster cell is seen by a set of observer points (Ruggles, Medyckyj-Scott, and Gruffydd, 1993; Wheatley, 1995; Kay and Sly, 2001; Wright, MacEachern, and Lee, 2014), fuzzy viewshed, which includes a calculation for the decay in the quality of vision over distance (Fisher,1994; Rášová, 2014), and probable viewsheds, which account for the effects of digital elevation model (DEM) uncertainty in their visibility calculation (Fisher, 1992; Fisher, 1994; Fisher, 1995; Rášová, 2014). The differences between the four methods are shown in Figure 2.

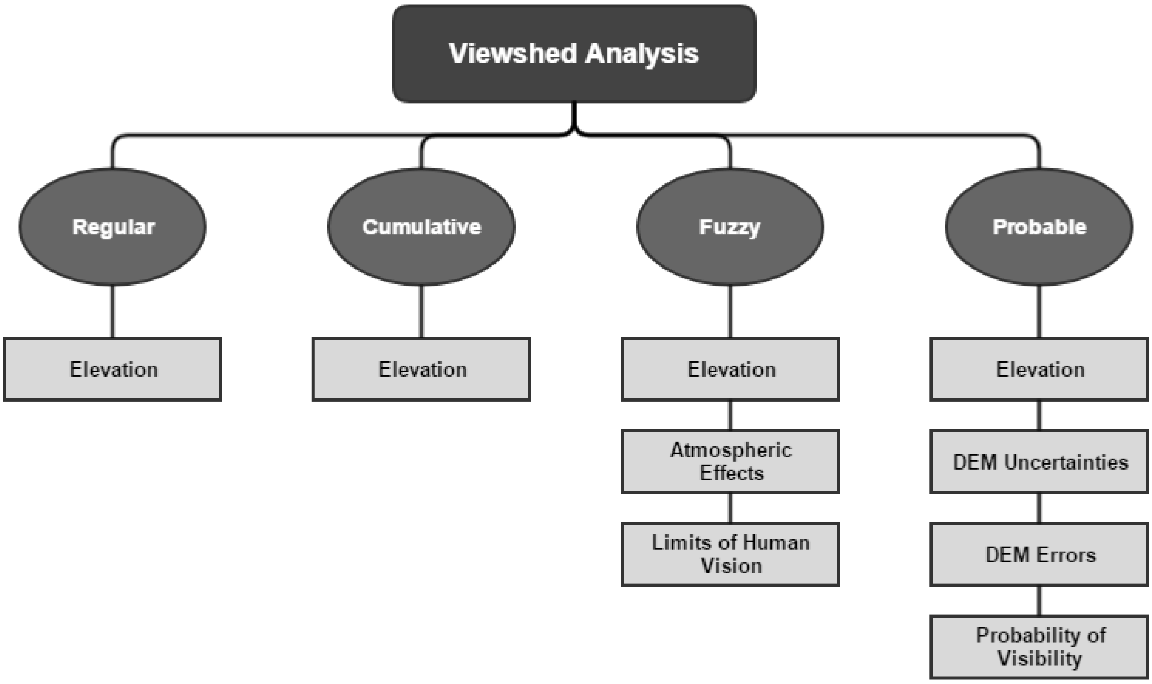

Figure 2: Comparison between Regular, Cumulative, Fuzzy and Probable viewshed analysis methods and the criteria taken into consideration during their calculation

4 Methodology

4.1 Data Acquisition

The data for this study comes from various sources. All location data for known Roman sites (towers, forts, and temporary camps) was extracted from Historic Environment Scotland's (HES) Canmore database. A series of CSV files were created, containing the national grid reference, name and Canmore database ID for each site. These files were imported into ArcMap, where the data was displayed and exported as a point shapefile. The Roman road data was downloaded from HES as vector shapefiles. The DEM is sourced from the Ordnance Survey Terrain 5 DTM elevation data, which has a cell size of 5m (Ordnance Survey, 2015). This was downloaded in raster tiles and mosaicked in ArcMap to create a continuous surface for use in further analysis. A hillshade and a slope map were derived from the DEM.

4.2 Viewshed Analysis

The first stage of the analysis was running regular viewsheds looking out from all of the tower locations across the landscape in southern Scotland. The height used for the towers in this study comes from the height given to towers along the Gask Ridge, a Roman road system in central Scotland. This fortified line is made up of forts, fortlets and at least 18 towers. Based on the dimensions of these towers (calculated from the remains of postholes for the main wooden support posts for the towers), they are generally accepted to have been between 7m and 10m in height (Woolliscroft, 2002). Due to the similarity in design and tower dimensions, this height has been used for this analysis. The standard height of an observer that is used in visibility analysis is 1.7m. Therefore, two offset heights (OffsetA and OffsetB) were added to the attribute tables for the tower points to account for the height of the tower plus the height of the observer. OffsetA is for the observer point, and OffsetB is for the observed point (what is being viewed from the tower) (ESRI, 2016a). Two viewsheds were run for each tower. The first was run with an offset of 8.7m (lower height of the tower plus the observer height), and the second was run with an offset of 11.7m (highest accepted height of the tower plus the observer height). This analysis resulted in the creation of 22 new data layers, eleven for the lower offset and eleven for the higher offset. These data layers were then used as the basis for further analysis, discussed below.

4.3 Cumulative Viewshed Analysis

The second stage of the visibility analysis was conducting cumulative viewshed analysis. The viewsheds that were created in the first stage of analysis were used for this stage. The eleven viewsheds at each height were added together using the Raster Calculator tool built into ArcMap. Raster calculator uses map algebra to execute various algebraic functions using the desired map layers for data. These calculations can range from simple addition (as seen in this application), to much more complex algebraic operations (ESRI, 2016b). This resulted in two cumulative viewsheds, one with an offset of 8.7m, and one with an offset of 11.7m. Each of these cumulative viewsheds show the total number of cells that are visible across the raster landscape from all of the sites (at the specified height offset), and indicate how many times each raster cell is visible (Ruggles, Medyckyj-Scott, and Gruffydd, 1993; Wheatley, 1995; Kay and Sly, 2001; Supernant, 2014; Wright, MacEachern, and Lee, 2014). This allows the user to visualize how many times each site is visible from other sites in the study, as well as which parts of the landscape are the least and the most visible from the towers. In this study, an individual cell was not visible more than six times at the lower offset and seven times at the higher offset.

4.4 Fuzzy Viewshed Analysis

The third stage of visibility analysis undertaken for this paper was fuzzy viewshed analysis. This analysis method provides a more realistic idea of what is visible from a specific point in the landscape, as it includes a decay function that demonstrates the breakdown in visibility over distance due to the limits of human vision and/or atmospheric effects on visibility. It moves away from the binary output of the regular viewshed (visible or not visible), and provides degrees of visibility over distance as you look out across the landscape from the observer point (Fisher, 1994; Ogburn, 2006; Rášová, 2014). This analysis involves multiple steps. The first is the creation of a Euclidean distance layer from each tower point. One of the optional input variables is the maximum distance that the Euclidean distance will be calculated for; for this study, the maximum distance was set at 60 km for all points. The new Euclidean distance layer for the observer point is then used in the distance decay calculation using Raster Calculator (see Equation 1).

$$\text{Con}(\text{euc\_dist} <= X, 1, \text{Con}(\text{euc\_dist} > X, (1/(1+(\text{Square}((\text{euc\_dist} – X)/ Y)))),0))$$

Equation 1: Distance Decay Calculation (Ogburn, 2006)

where:

- euc_dist is the Euclidean distance layer from the observer point (also controls the maximum extent of the decay function and the viewshed)
- X is the limit of perfect visibility, in metres
- Y is the limit beyond which visibility greatly decreases, in metres

For this study, the limit of perfect visibility (X) was set to 20km, and the point for the decrease in visibility (Y) was set to 40km. The maximum distance of 60km is based on what was visible while conducting fieldwork and from distance measurements for landmarks identified in photographs taken from the summit of Rubers Law. The X and Y values are 1/3 intervals of the maximum distance, and were entered into the calculation in metres. The new decay layer was then multiplied against the regular viewshed for each offset height at each tower location. This outputs a fuzzy viewshed with a gradient of visibility between 0 and 1, where cells with a value of 0 are not visible and cells with values approaching 1 are more visible. Cells closest to the observer point will have values at or closest to 1, and these cell values will approach 0 as you move away from the observer point.

4.5 Probable Viewshed Analysis

The fourth type of analysis applied to this paper is probable viewshed analysis. Probable viewsheds represent the “probability of a location [in the landscape] being visible from the [observer] point” (Fisher, 1995, 528). They allow for some of the errors and uncertainty that are associated with DEMs and regular viewsheds to be considered in the calculation of the viewshed. They also allow the user to determine if viewshed results are due to actual intervisibility, or if it is a result of DEM error (Fisher, 1995; Rášová, 2014). According to Fisher (1994), probable viewsheds show us the areas in the landscape that should be visible from an observer point. Probable viewsheds are calculated using a Monte Carlo simulation of error. This process creates several variations of the DEM, based on the root mean square error. Viewsheds are then created for each of these variations, and these new viewsheds are added together to find the probability of any point in the landscape being visible from the original observer point(s) (Fisher, 1994). A complex calculation is required to complete this process, but there is a toolbox, developed by Rášová (2013), available for download through the ArcGIS online resources page. This tool requires the user to input the observer points, the DEM base raster layer, and the number of realisations of the viewshed (the default is 20). The user can also set the refractivity coefficient (the numerical representation of the refraction of visible light in the air, default of 0.13) (Rášová, 2014). For this paper, the Roman tower locations across southern Scotland were used for the observer points, the OS DEM was used as the base raster, and the rest of the inputs were left at their default settings. This analysis was run for each individual observer point, as well as for the group as a whole to see if it produced differing results.

4.6 Digital Image of Visible Landscape

To add a phenomenological perspective to this paper (Rennell, 2012), a series of photographs were taken from the triangulation point on the summit of Rubers Law in order to create a record of the visibility on the two days of fieldwork (see Figure 2). A Canon EOS Rebel T3i DSLR camera with a Canon 24-105 EF USM L series lens was placed on top of the triangulation point, and photographs of the surrounding area were taken in a full circle from this point. These photographs were then stitched together to produce 360° panoramas of the landscape surrounding Rubers Law. The first panorama is composed of 19 photographs, and the second is composed of 24 photographs. Visibility on the first day was moderate, as there was significant atmospheric haze. Visibility on the second day was excellent, and likely represents an ideal visibility situation from Rubers Law (see Figure 3). Several other large hills are visible from the summit, and based on these images, distance measurements were taken in ESRI's ArcGIS software to find the maximum distance for the fuzzy viewshed.

Figure 3: Visibility comparison between Day 1 (left) and Day 2 (right) of fieldwork on Rubers Law, looking north towards the Eildon Hills

5 Results and Discussion

5.1 Viewshed Analysis

After running the regular viewshed analysis on the eleven Roman towers in southern Scotland, there are some divisions in the data. Rubers Law, Eildon Hill North, Craik Cross Hill, and Brownhart Law all have much larger and overlapping viewsheds (see Figures 4-7); conversely Beattock Summit, Butterhole Brae, Carmaben Hill, Ewes Doors, and White Type all have much smaller and more localised viewsheds (see Figure 8). Barron's Pike and Robin Hood's Butt, which are located just south of the Scottish-English border, have larger viewsheds, but look mostly to the west and the south, and do not have a large overlap with the viewsheds of the towers located in Scotland (see Figure 8). This is the case for the analysis at both offsets, which resulted in very similar viewsheds. The difference in the size of the viewshed suggests that there are two sets of towers, each serving slightly different purposes. The more localised viewsheds of the second set of towers are all found directly on the line of confirmed or suspected Roman roads in the west of the study area. This placement indicates that they were likely placed at key points to watch over the line of the road, and to be able to raise the alarm in case of any problems in that region. The viewsheds of Rubers Law, Craik Cross Hill, Eildon Hill North and Brownhart Law all cover a large area and have a large amount of overlap. The regular viewsheds for these sites indicate that they are all intervisible, and that they could have sent signals to each other. From these results, the towers were placed into two groups. Group A consists of Rubers Law, Eildon Hill North, Craik Cross Hill, and Brownhart Law, while group B contains Beattock Summit, Butterhole Brae, Carmaben Hill, Ewes Doors, White Type, Barron’s Pike, and Robin Hood’s Butt.

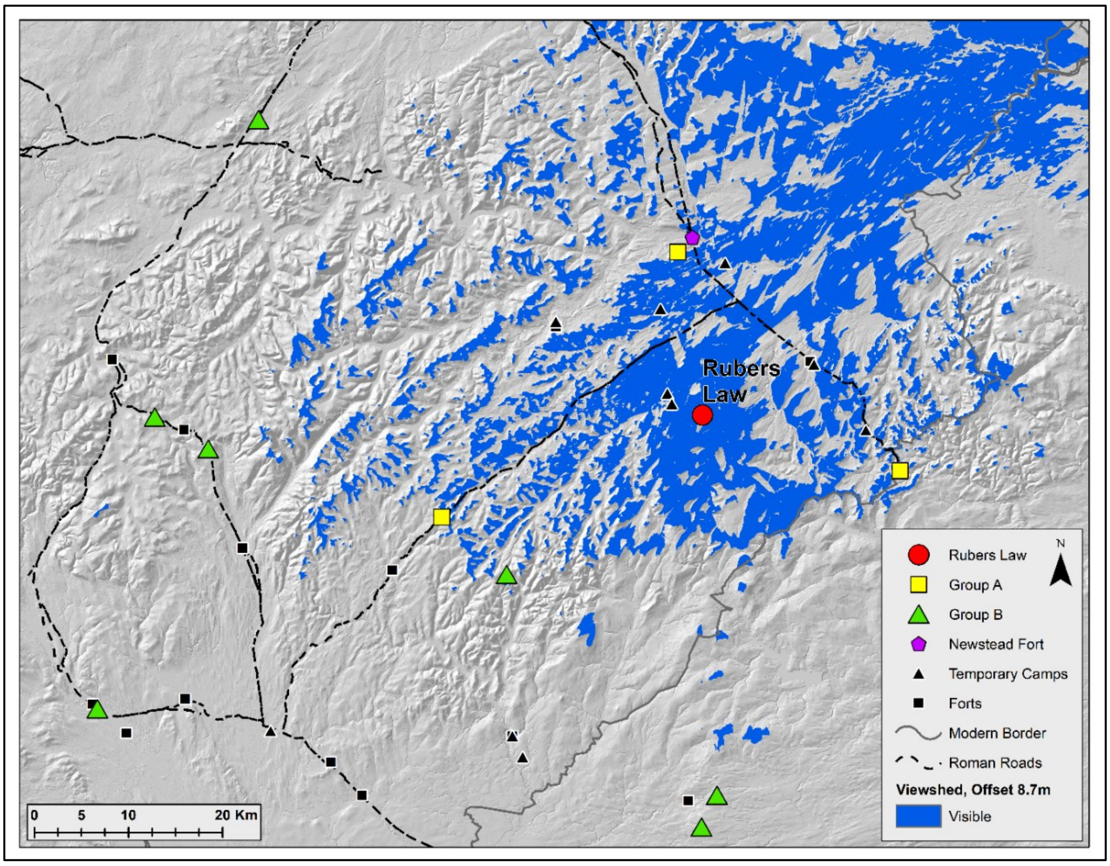

Figure 4: Regular viewshed for Rubers Law with an offset of 8.7m

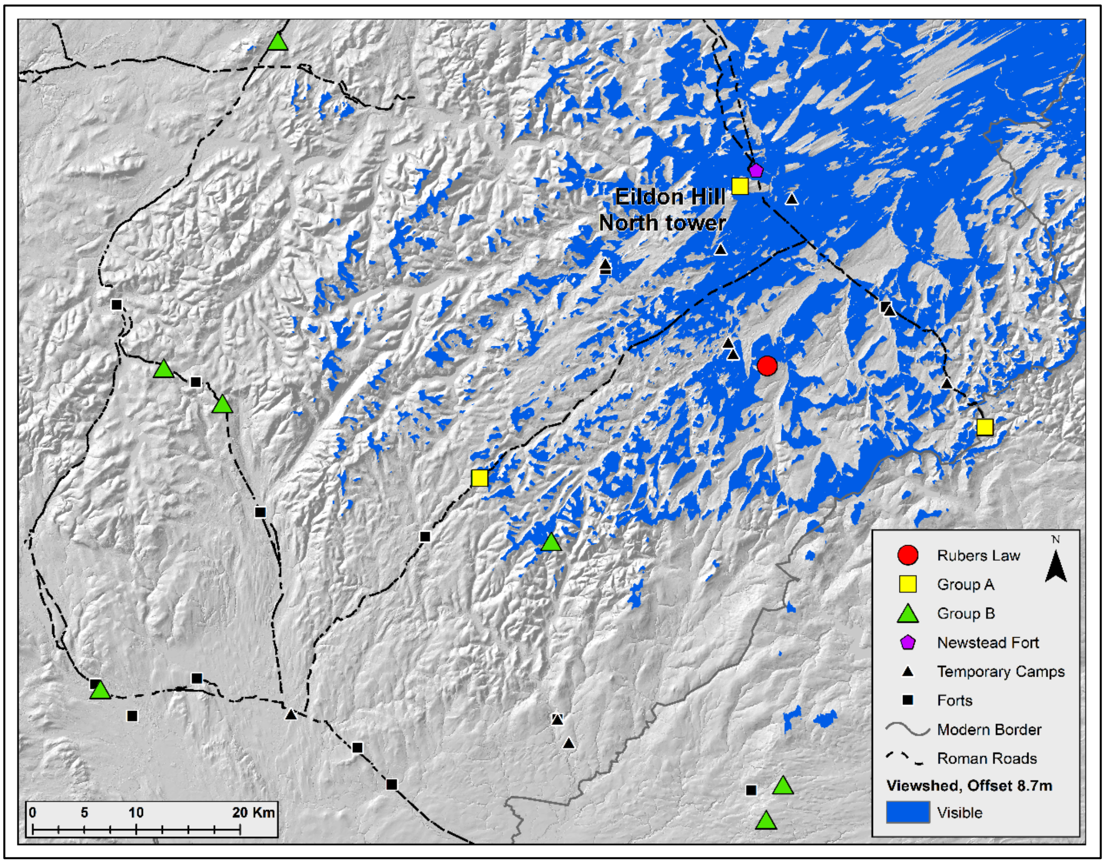

Figure 5: Regular viewshed for Eildon Hill North with an offset of 8.7m

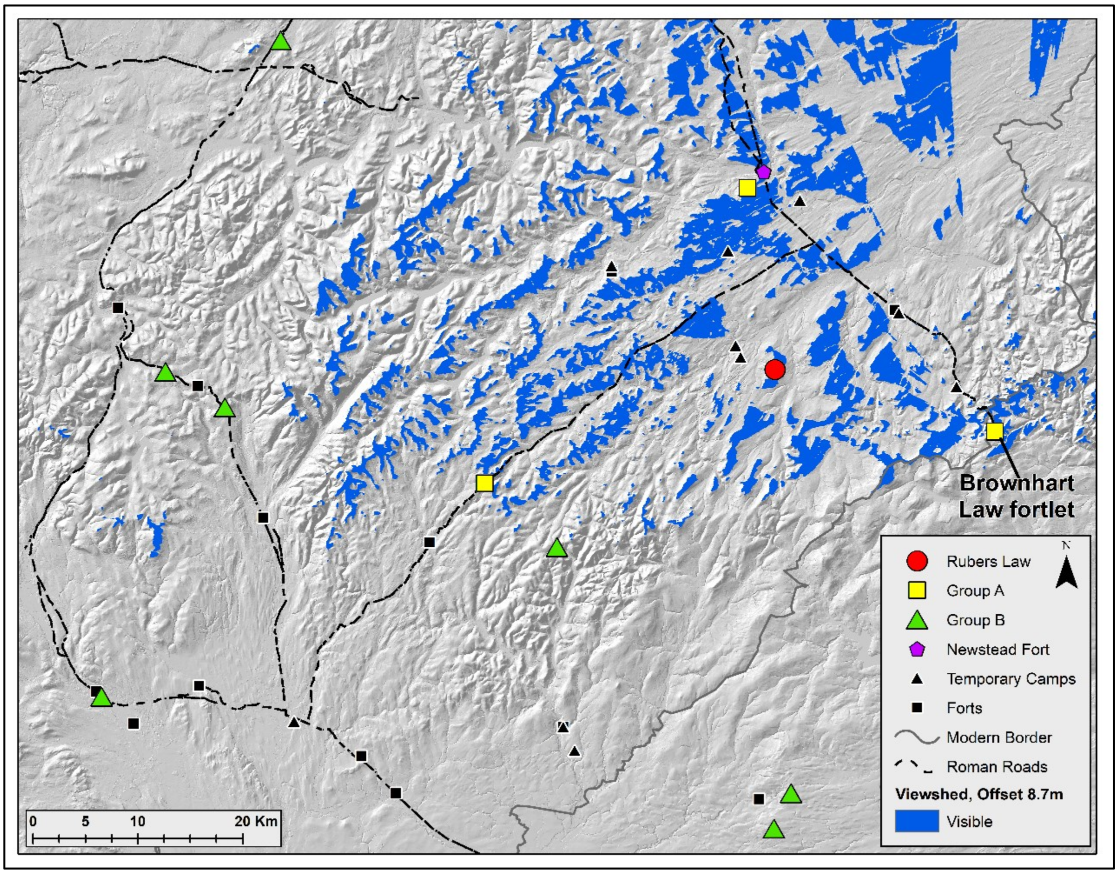

Figure 6: Regular viewshed for Brownhart Law with an offset of 8.7m

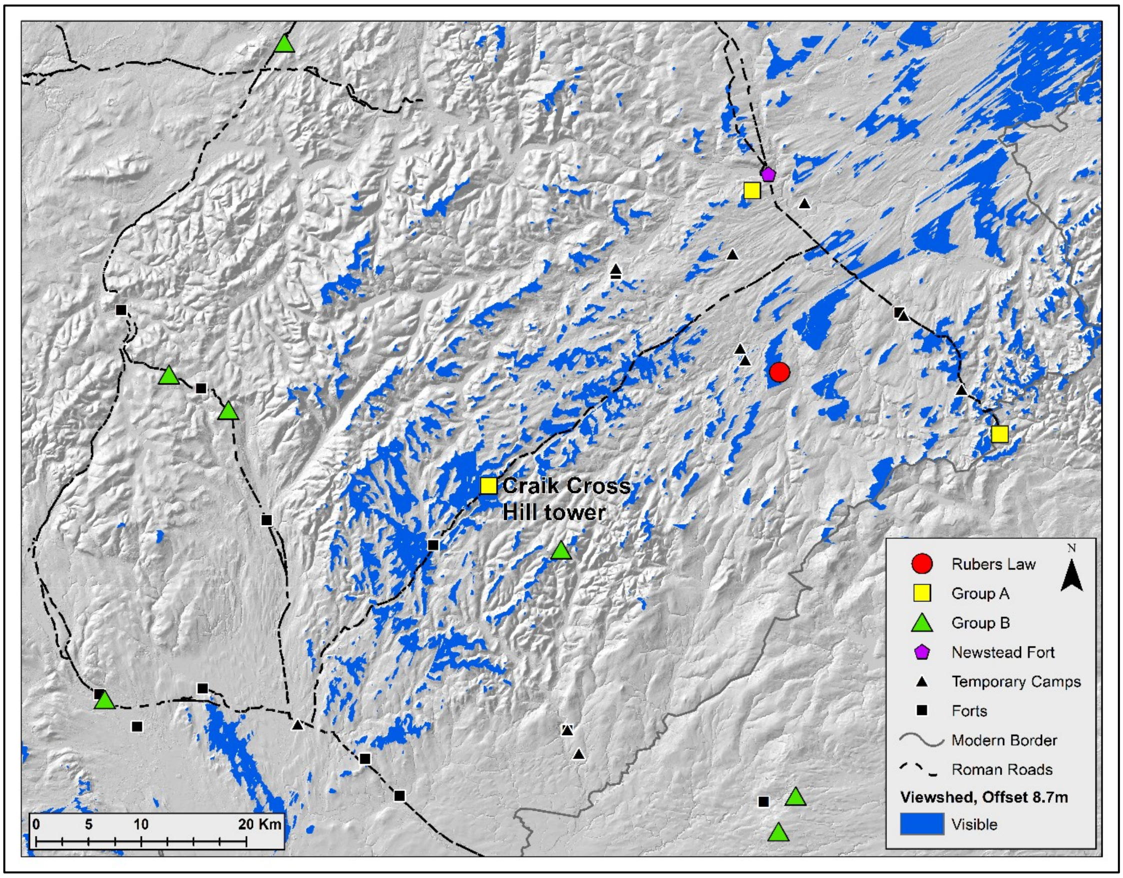

Figure 7: Regular viewshed for Craik Cross Hill with an offset of 8.7m

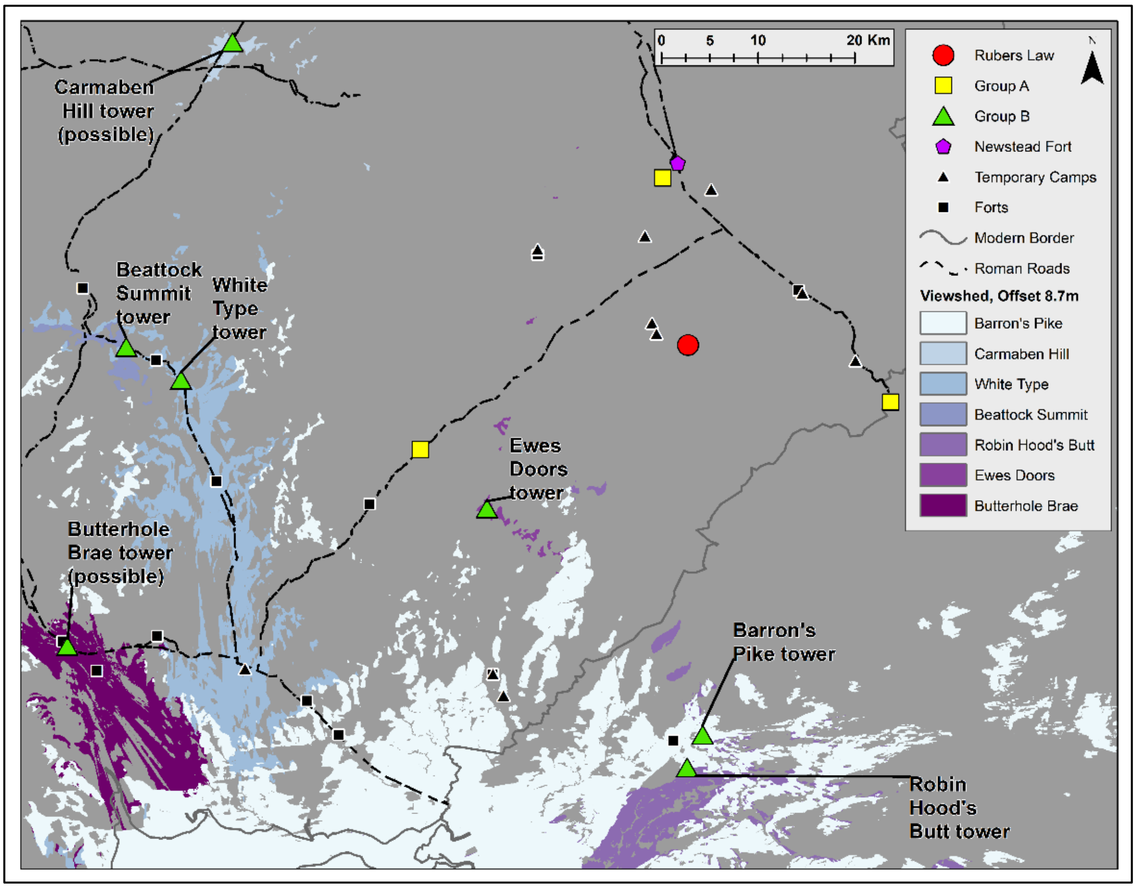

Figure 8: Regular viewsheds for the Group B towers (Barron's Pike, Beattock Summit, Butterhole Brae, Carmaben Hill, Ewes Doors, Robin Hood's Butt & White Type) with an offset of 8.7m

5.2 Cumulative Viewshed Analysis

Two cumulative viewshed layers were created using the above described methodology (see Figure 9 and Figure 10). By combining the eleven individual viewsheds for each offset height, we can find out how many times each cell is seen from the towers, as well as how many times each tower is seen by the other towers. No cells in the raster landscape are seen more than five times by the Roman towers.

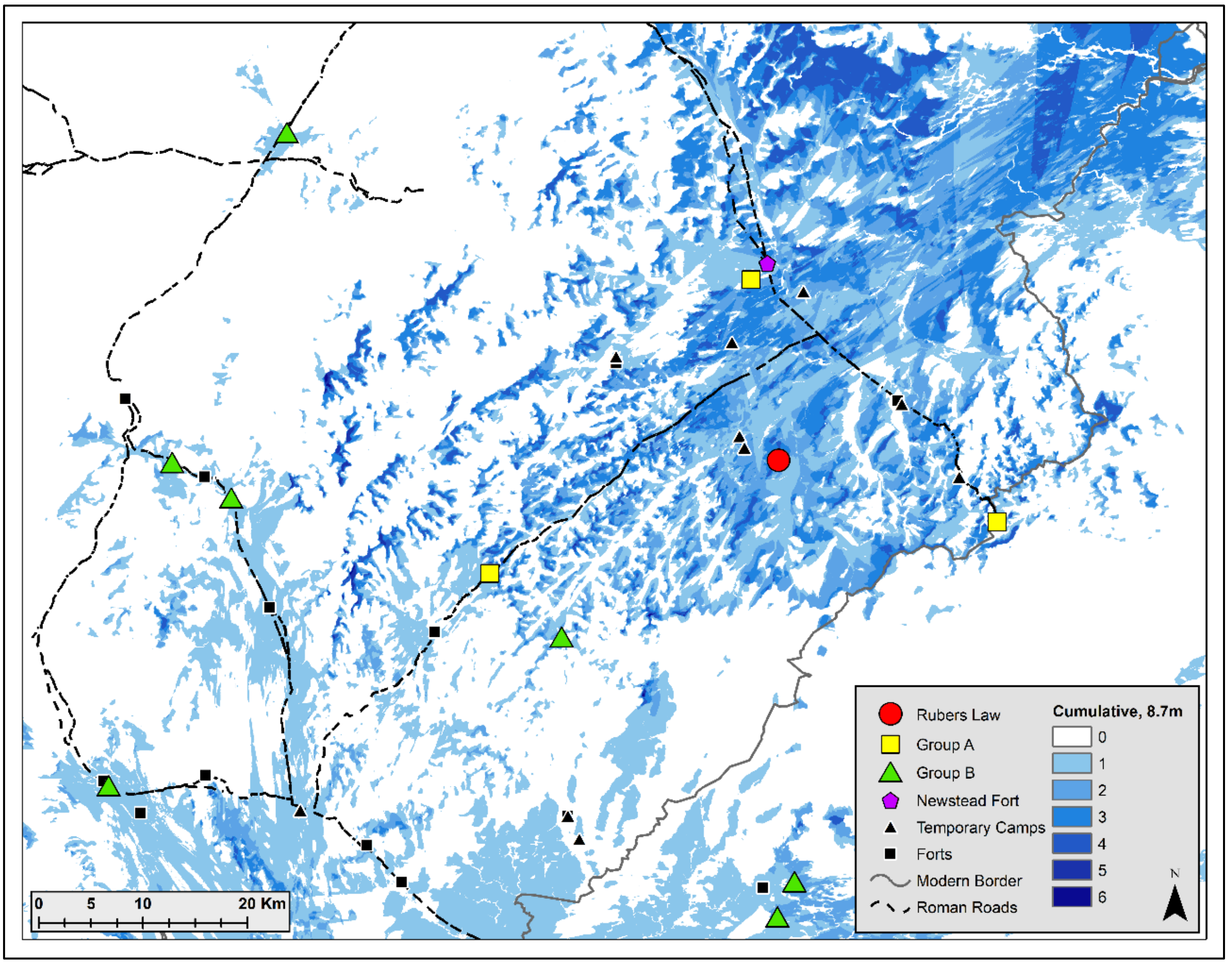

Figure 9: Cumulative Viewshed for the Rubers Law Study area with an offset of 8.7m

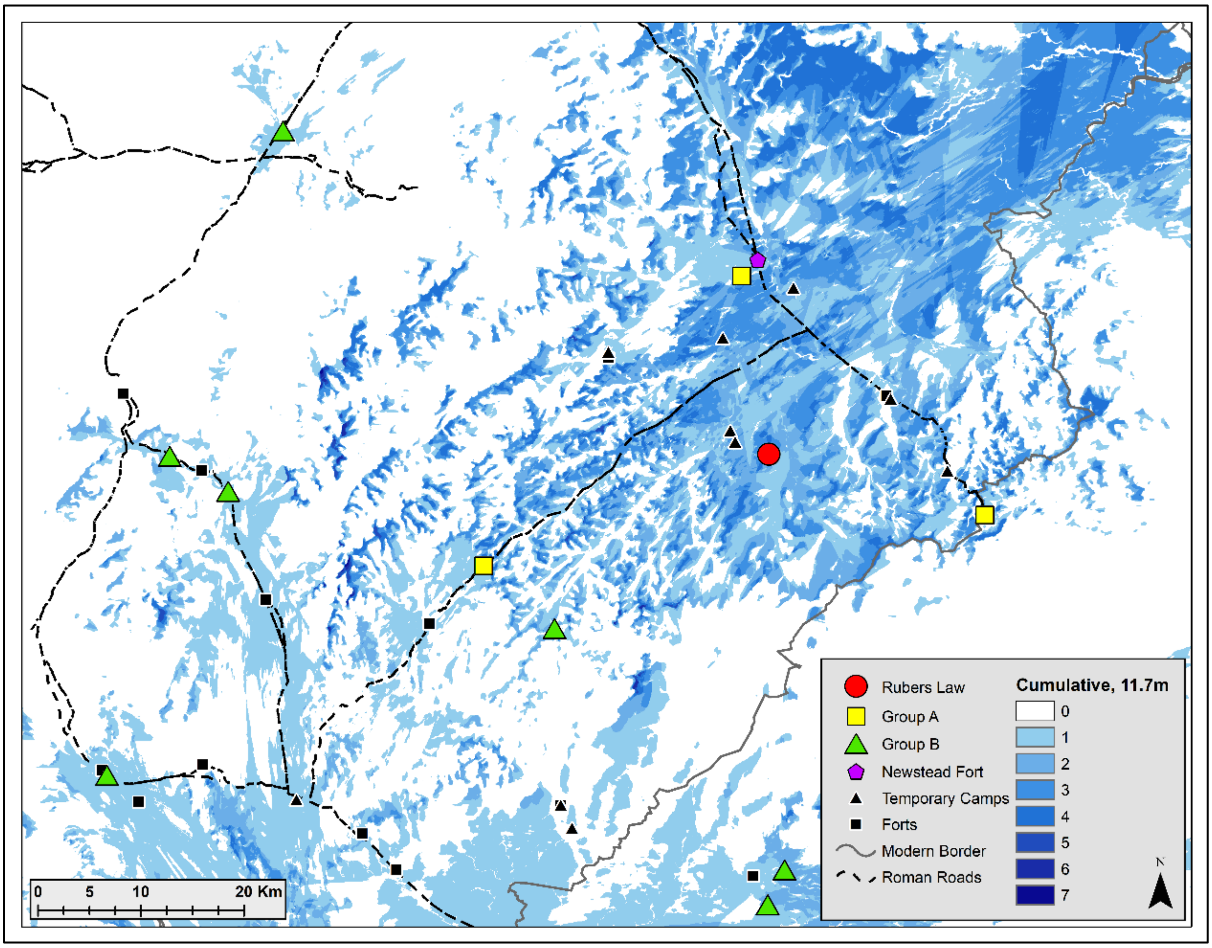

Figure 10: Cumulative Viewshed for the Rubers Law Study area with an offset of 11.7m

Table 1 provides the total number of visible cells for each offset height, and how many times those cells are seen from the towers. Based on this analysis, there is an increase in the total number of cells that are visible at the higher offset of 11.7m, meaning a larger portion of the landscape is visible with the 3m height increase of the second offset (see Table 1).

Table 1: Number of visible cells for each offset height and number of times seen from the towers based on Cumulative Viewshed Analysis

Number of Views	# of Cells Visible at 8.7m Offset	# of Cells Visible at 11.7m Offset
0	719,210,648	701,965,841
1	96,385,378	94,356,078
2	49,670,998	60,172,280
3	29,112,664	34,841,284
4	9,241,602	12,114,846
5	336,758	438,114
6	31,245	89,960
7	---------------------------------	10,890
Total Number of Visible Cells	**184,778,645**	**202,023,452**
Total Number of Cells	**903,989,293**	**903,989,293**

There is an increase in the amount of overlap between the viewsheds and the total number of visible cells from the towers with an offset of 11.7m (see Table 1). This increase in height results in an 8.5% increase in the total number of visible cells from the towers. With the increase in height, the observer at the tower would generally be able to see more, and if your target (for signal reception) is taller, it has a higher chance of being seen above the surrounding landscape or vegetation. This logic can also be applied to the signals themselves, as a signal fire that is higher than the surrounding landscape and vegetation is going to be easier to see.

Table 2 shows how many times each tower is seen by other towers in the region. These figures are the same at both offset heights, and while there is an increase in total visible area, there is no increase in intervisibility with an increase in height. Rubers Law, Eildon Hill North, Brownhart Law, and Craik Cross Hill are all highly visible in the landscape, as they are all seen by three other towers (they are all intervisible at both offsets). Barron’s Pike and Robin Hood’s Butt are intervisible with each other; they may connect with sites near or along Hadrian’s Wall, but that analysis is outside the scope of this study. Carmaben Hill, Beattock Summit, Butterhole Brae, Ewes Doors, and White Type are the least visible, as they are not seen by any other towers in the region, and most likely provided a more localised service.

Table 2: Number of times each tower is seen by other towers in the study area

	Observer Point	**Number of views at both offset heights**
Group A	Rubers Law	3
	Eildon Hill North	3
	Brownhart Law	3
	Craik Cross Hill	3
Group B	Barron’s Pike	1
	Robin Hood’s Butt	1
	Carmaben Hill	0
	Butterhole Brae	0
	Ewes Doors	0
	White Type	0
	Beattock Summit	0

The data in Table 1 supports a view that the primary purpose of these towers was to watch over the surrounding landscape, and that by increasing the height, there is an overall increase in the area that is visible from the tower. The potential for point to point signalling is shown in Table 2, as the group A towers are all intervisible at both offsets, and would therefore be able to signal to one another. Table 2 also shows the division in the towers included in this study, as the group B towers are not invisible with any other towers, and indicates that the primary purpose of the group B towers would likely have been to watch over a localised area along the Roman roads.

It should be noted that the cumulative viewshed is created using regular viewsheds, and therefore does not take a decay in the quality of human vision over distance, atmospheric effects on light and vision, or extreme distances into account. The use of fuzzy viewshed is one way to overcome these issues, and the results of that analysis are discussed below.

5.3 Fuzzy Viewshed Analysis

For the fuzzy viewshed analysis, the decay on visibility begins at 20km, with a significant drop off in the quality of visibility after 40km, and a maximum visibility distance of 60km. These distances are set for ideal visibility conditions, as seen on the second day of fieldwork (see Figure 3), and they would be expected to decrease significantly on days with poor weather conditions such as haze or fog. From Rubers Law, the group A towers fall within these boundaries (for exact distances see Table 3). Eildon Hill North falls within the 20km perfect visibility buffer, while Brownhart Law and Craik Cross Hill are just outside the area of perfect visibility (see Figure 11). The fuzzy viewshed values range from 0 to 1, with values closest to or equal to 1 being the most visible. Eildon Hill North is the most visible from Rubers Law, with a viewshed value of 1, while Brownhart Law is at a value of 0.998. Craik Cross Hill is the furthest away from Rubers Law, but is still within the top 6% of visibility at 0.945. The viewshed visibility values are the same at both offset heights, and are the same when looking out from Rubers Law or back towards it from the other tower locations (see Table 3). The group B towers fall within the visibility limits, however they do not fall within the viewsheds of any of the group A towers.

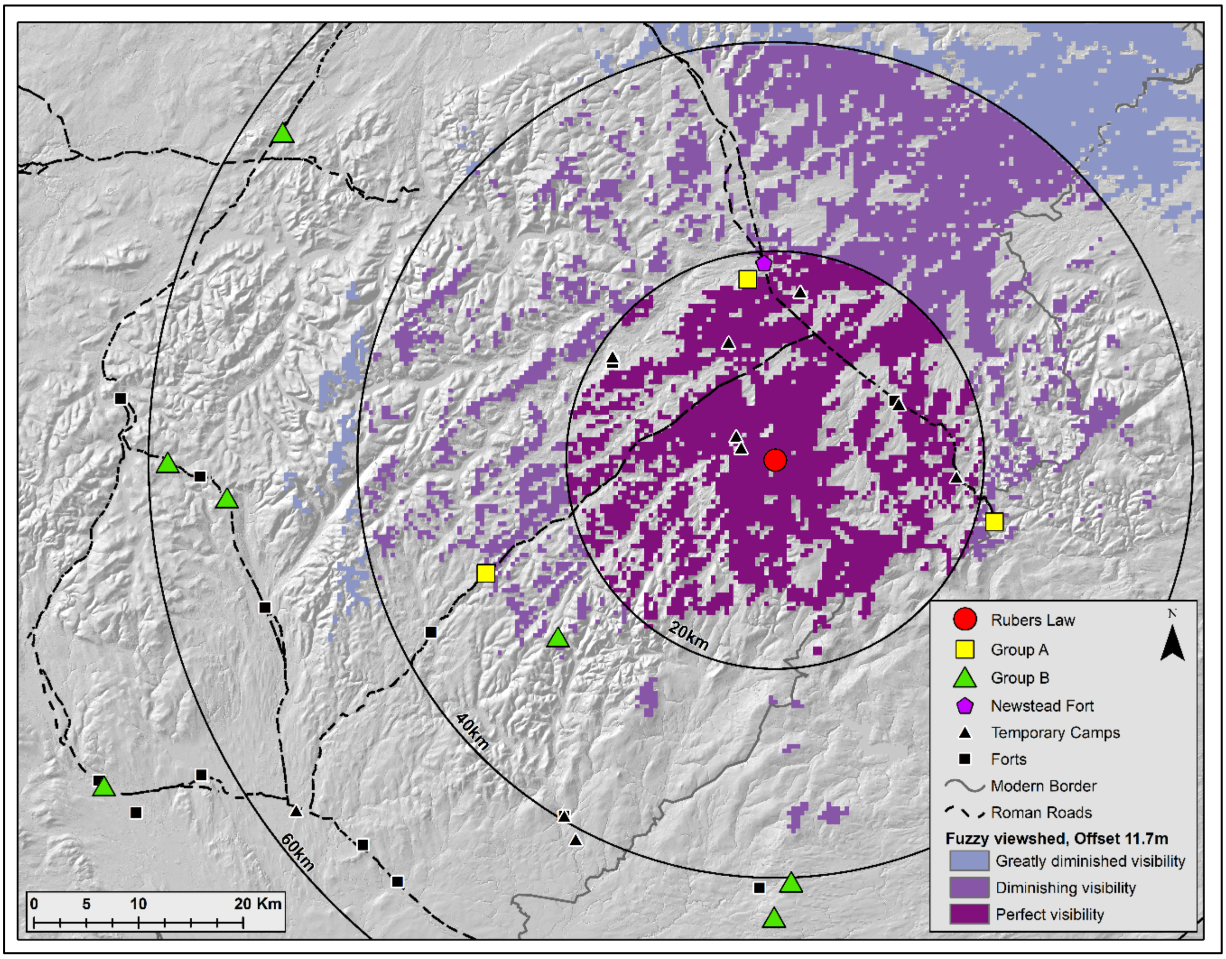

Figure 11: Fuzzy viewshed analysis from Rubers Law with an offset of 11.7m

Table 3: Distance and Viewshed Values between Rubers Law and the Group A towers

Tower	Distance to Rubers Law (km)	Viewshed value 8.7m offset	Viewshed value 11.7m offset
Eildon Hill North	17.5	1	1
Brownhart Law	21.8	0.998	0.998
Craik Cross Hill	29.7	0.945	0.945

While the visibility between Rubers Law and its nearest neighbouring towers is very good, there is a decrease in visibility between the remaining group A sites. The distances between the sites is greater, and the three sites are located either in the zone where visual degradation begins or the area where visibility greatly decreases (see Figures 12-14). Craik Cross Hill has the lowest visibility values, and it is located the furthest from the other towers (see Table 4 and Table 5). Eildon Hill

North and Brownhart Law have a visibility value of 0.903 with each other, which is still fairly high, but when compared to the visibility between these sites and Rubers Law, it is an almost 10% decrease in the visibility value. The distance over which a signal would be sent is also much further than if it were to be relayed via Rubers Law.

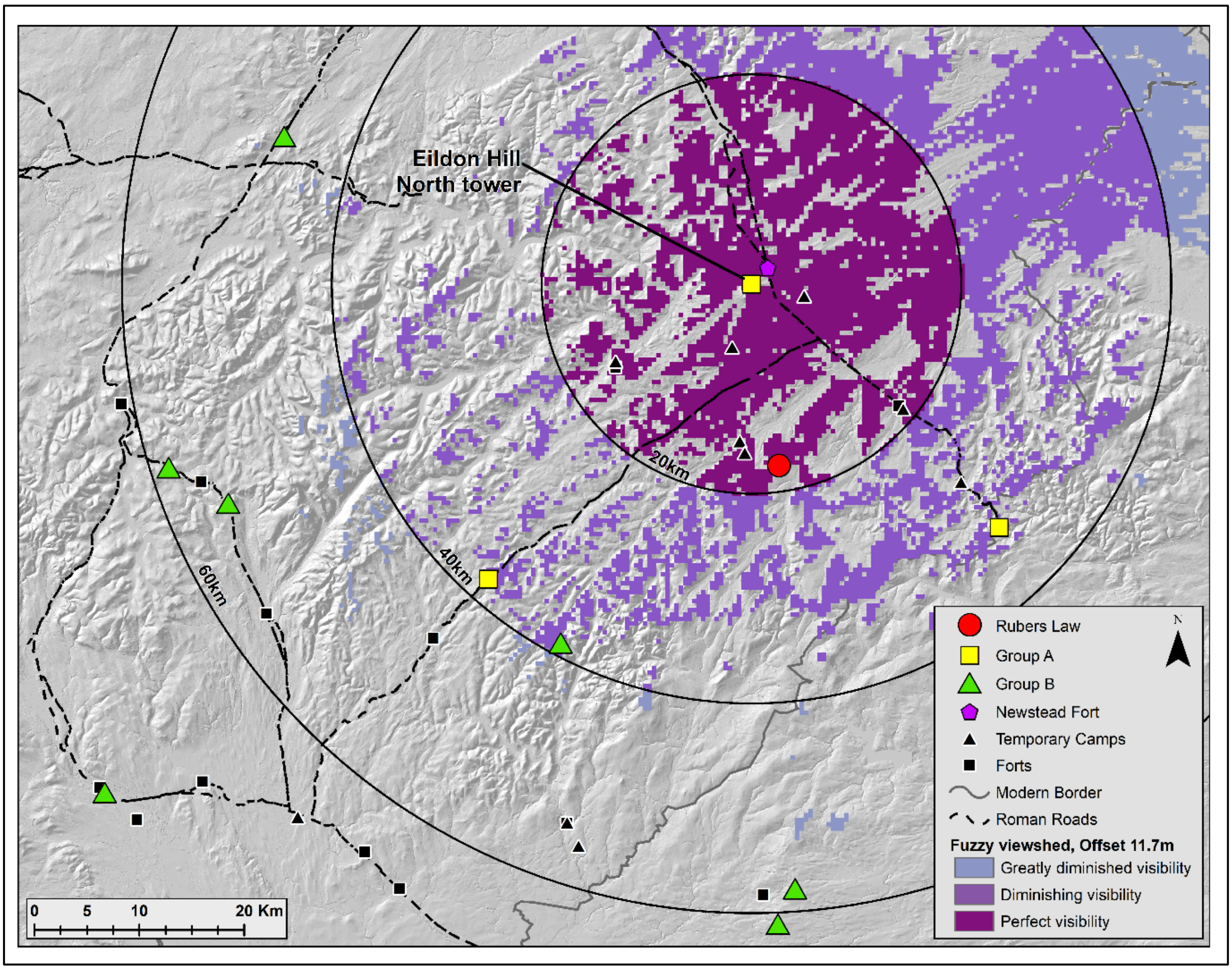

Figure 12: Fuzzy Viewshed Analysis for Eildon Hill North with an offset of 11.7m

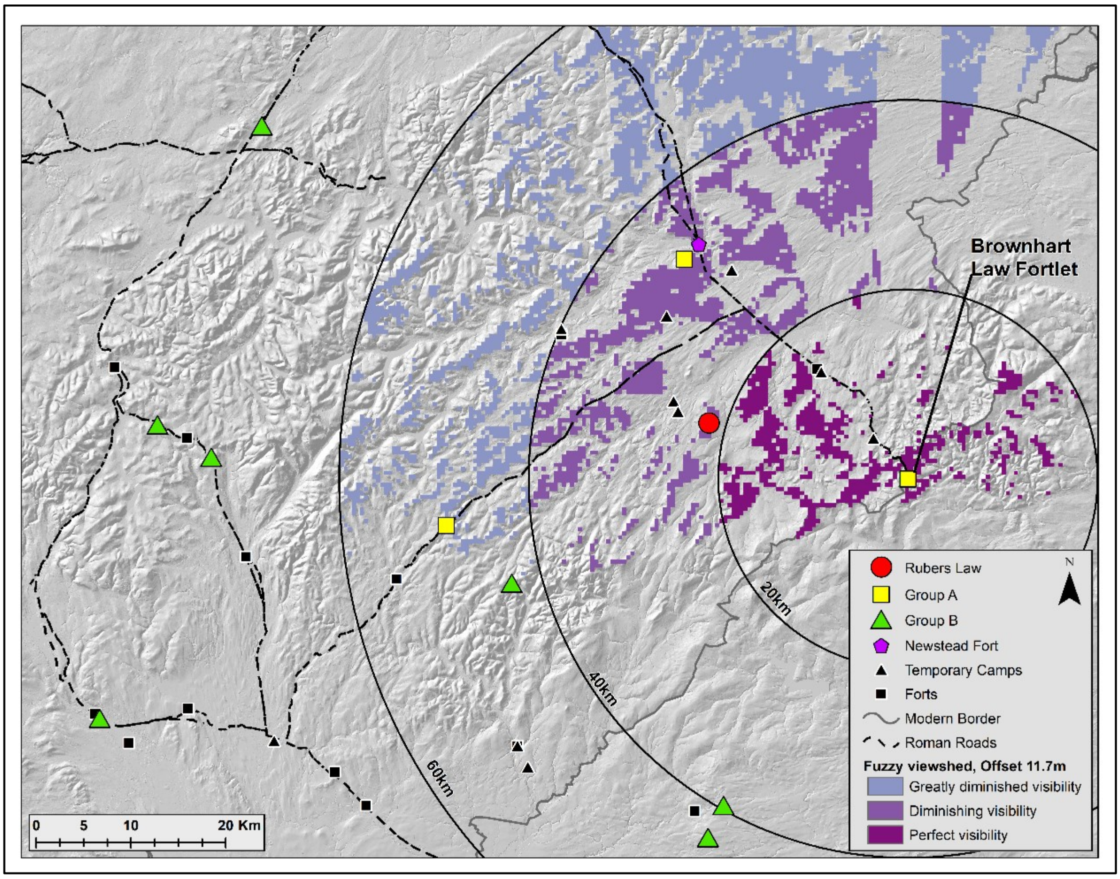

Figure 13: Fuzzy viewshed analysis for Brownhart Law with an offset of 11.7m

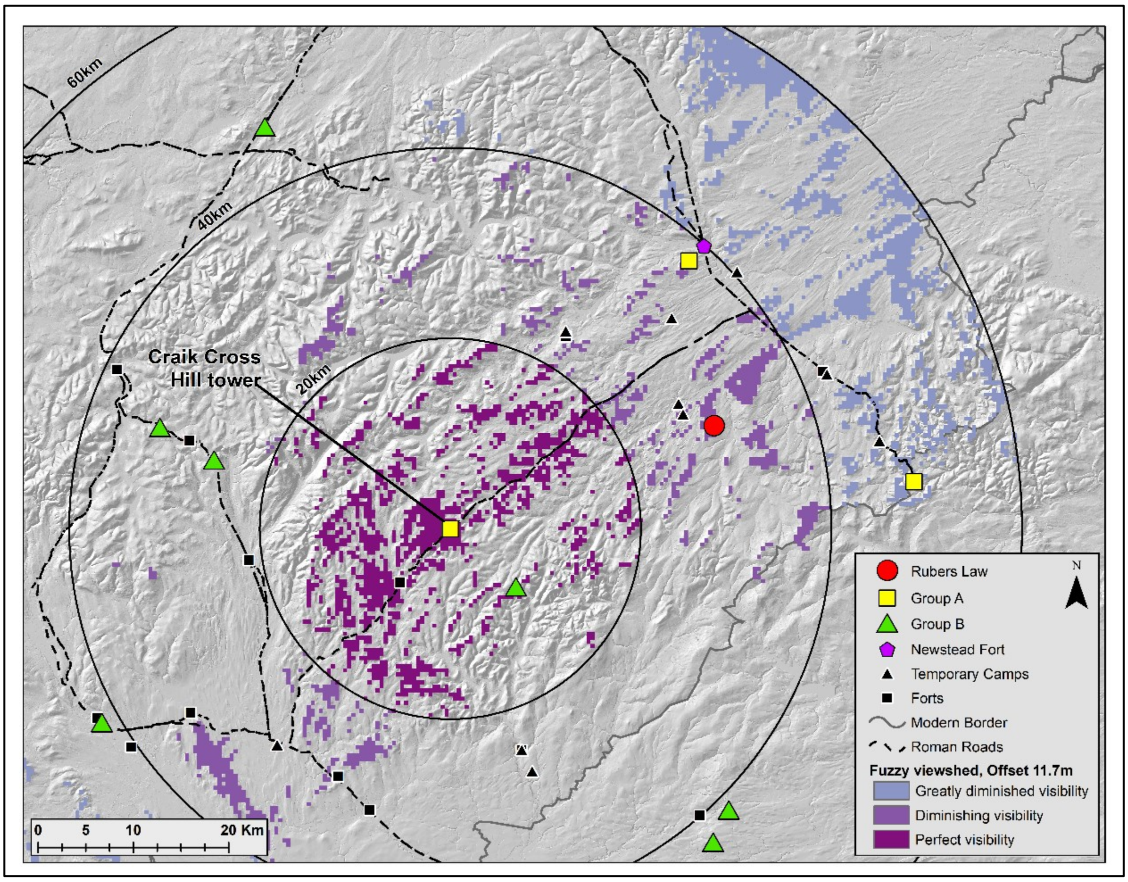

Figure 14: Fuzzy viewshed analysis for Craik Cross Hill with an offset of 11.7m

Table 4: Visibility Values between Rubers Law's nearest neighbouring towers

To/From	Eildon Hill North	Craik Cross Hill	Brownhart Law
Eildon Hill North	----------------------------	0.836	0.903/0.907
Craik Cross Hill	0.836	----------------------------	0.658
Brownhart Law	0.903	0.659	----------------------------

Table 5: Distances between Rubers Law's nearest neighbouring (Group A) towers

Sites	Distance (km)
Eildon Hill North to Craik Cross Hill	37.7
Craik Cross Hill to Brownhart Law	48.9
Brownhart Law to Eildon Hill North	33.1

This analysis indicates that the intervisibility between Rubers Law and its nearest neighbouring towers is very good. Based on these results, if there was a Roman tower on the summit of Rubers Law, it may have acted as a relay station for signals and messages between the other group A towers. Craik Cross Hill and Brownhart Law are both found along known Roman roads that lead to Newstead Roman Fort, which is located at the base of Eildon Hill North. If Rubers Law was a relay station, it could have sent warning signals from Craik Cross Hill and/or Brownhart Law to Eildon Hill North, where these warnings could be passed to Newstead to raise the alarm in case of any problems or enemies that may be moving towards the fort.

5.4 Probable Viewshed Analysis

The probable viewshed represents the probability of a cell in the viewshed raster being seen, while accounting for the inaccuracy and potential errors in the DEM that was used to run the analysis (Fisher, 1995; Rášová, 2014). In this case, a cumulative probable viewshed was run, as it includes all eleven towers in the analysis. The nature of the method has given rise to a lower resolution viewshed than observed in previous figures. The resulting output layer has cells with values between 0 and 7; the closer the cell value is to 7, the higher the probability of it being seen in the landscape (see Figure 15). Based on this analysis, Rubers Law and the group A towers have probability values of 4 or 5 (see Table 6). These high probability values indicate that these towers are intervisible with each other. The group B towers have a probability of 1 or 2 of being visible, and therefore have a much lower probability of being seen by any of the other towers in the study. These values are based on 20 iterations of Monte Carlo simulations of the viewsheds from these eleven sites. The results from this analysis show that DEM error is not the reason that each site is visible, and that visibility of the sites is based on actual intervisibility between the towers (Fisher, 1995; Rášová, 2014).

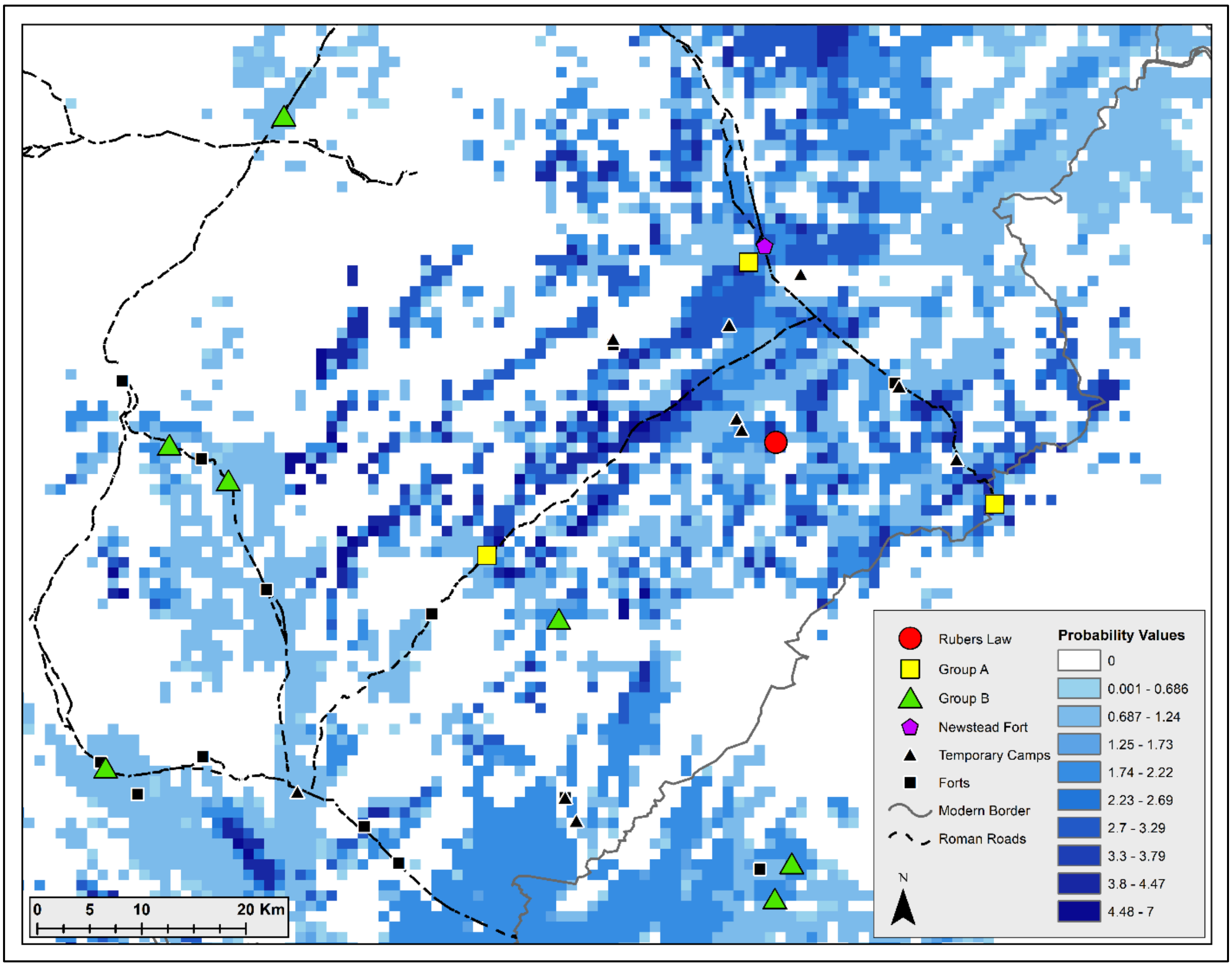

Figure 15: Probable viewshed analysis for the Rubers Law study area

Table 6: Probable viewshed values for the Roman towers in southern Scotland

	Site	**Probable Viewshed Value**
Group A	Rubers Law	4
	Craik Cross Hill	4
	Eildon Hill North	5
	Brownhart Law	4
Group B	Barron’s Pike	2
	Beattock Summit	1
	Butterhole Brae	1
	Carmaben Hill	1
	Ewes Doors	2
	Robin Hood’s Butt	2

	White Type	1

5.5 Purpose of Rubers Law

While most publications follow Curle’s conclusions about Rubers Law, Keppie (1990) is more sceptical of the Roman stones and their association with a signal station. He concludes that the stones more likely originated from a nearby Roman structure (yet to be located) that the medieval occupants of Rubers Law decided to use as a source of material for their fort. One of the potential issues with the conclusion that the Roman stones on the summit of Rubers Law represent the presence of a stone tower is that all other known Roman towers north of Hadrian’s Wall are built out of timber. In fact, with the exception of one highly unique site, all detached Roman features north of Hadrian’s Wall are built out of timber, including the fortifications of major forts and other military installations. The unique site, and only example of a stone structure, is Arthur’s O’on, located in Stenhousemuir (RCAHMS, 1965; Brown, 1974; Brown and Vasey, 1989). The closest comparable tower to what could have been built on Rubers Law is Robin Hood’s Butt, which is found 44km south, across the modern Scottish-English border in Cumbria. The remains of a square stone structure were found on a small rise, and was likely placed to transmit messages to Birdoswald Roman fort (Richmond, 1933).

Without further archaeological investigation, it is not possible to definitively state if there was a tower on the summit of Rubers Law, but, based on the viewshed analysis carried out in this study, it is likely that Rubers Law did have a role to play in the Roman occupation of southern Scotland. With the excellent intervisibility with the rest of the group A towers in the region, Rubers Law could be a major link in the communication network north of Hadrian’s Wall. It has commanding views across the Teviot valley, giving Rubers Law the ability for point to point visibility with neighbouring towers, as well as the ability to watch over a section of the Roman road and several temporary camps located just to the north of the hill. This could be part of a wider system that stretches northeast towards the estuary of the river Tweed.

6 Conclusion

Upon completion of this analysis, it is clear that the different viewshed analysis methods provide differing results on what is and what is not visible in the landscape. The regular viewshed analysis suggests that Rubers Law and the group A towers are all intervisible and would have had the ability to communicate with each other. They also show that the towers that are further away, particularly Beattock Summit, Carmaben Hill, Butterhole Brae, and White Type had much more localised viewsheds and likely monitored movement along sections of the Roman road network. These results are supported by the cumulative viewshed analysis, but this was run using the same regular viewsheds. The cumulative viewshed is interesting, as it provides an indication of the areas where the viewsheds overlap, and what areas of the landscape are the least and the most visible. Both the regular viewshed and the cumulative viewshed analysis over predict the visibility from the towers, as they are based purely on the heights from the DEM, and do not account for any other effects on visibility. The fuzzy viewshed results give a more realistic idea of what the visibility from each site would be, as it includes a decay function to account for the decrease in the quality of human vision over distance and the effects of the atmosphere on visibility. This analysis indicates that the visibility between Rubers Law and its nearest neighbouring towers is very good, while the intervisibility between those neighbouring towers is greatly decreased in comparison. The probable viewshed analysis provides insight into the effects of DEM error on the viewshed results. The analysis conducted for this study indicate that the group A towers have the highest probability of being visible from the other sites. These results support what was found in the fuzzy viewshed analysis. The group B towers have a lower probability of being visible from the other towers, which supports the results of the initial, regular viewshed analysis. Thus, we have shown the likelihood of group A towers forming part of an inter-communicating network, while group B towers have localised visibility over specific features (e.g. roads), except for Ewes Doors which has a remarkably limited viewshed. This difference in function could also represent differing periods of use.

Based on this analysis, a Roman tower located on the summit of Rubers Law would have a commanding view of the surrounding landscape. With height offsets of 8.7m and 11.7m, the site is intervisible with Craik Cross Hill, Brownhart Law and Eildon Hill North. These three sites have poor intervisibility with each other. From this, it is possible that a tower on Rubers Law would have formed a crucial part of this inter-commutating network. With the location of Craik Cross Hill and Brownhart Law on the lines of known Roman roads that lead to Newstead Roman Fort (located at the base of the Eildon Hills), Rubers Law could have relayed signals from these two towers and passed them on to Eildon Hill North, where soldiers would be able to raise the alarm at Newstead Roman fort.

This analysis indicates that there are limitations to the results of regular, binary viewsheds. They over predict the visible landscape, and the intervisibility between archaeological sites and features in that landscape. They can be used as a starting point for visibility analysis for a region, as they can highlight patterns or divisions in the data (as seen here between the group A and group B towers). To gain a better understanding of what can be seen across a landscape, more robust visibility analysis is needed. This can be conducted using fuzzy and probable viewshed analysis, to ensure that other potential effects on the visibility results are included in the analysis. These methods include the limitations of human vision, the effects of the atmosphere on visibility, and the inherent error in DEMs in their calculations.

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